National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

What is the A-Train Telling Us about Atmospheric Water Vapor (and other feedbacks)?

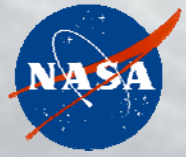
Eric J. Fetzer

Jet Propulsion Laboratory, California Institute of Technology

Workshop on Climate Feedbacks
and Future Remote Sensing Observations
Caltech, September 2, 2009

Copyright 2009 California Institute of Technology

Eric.J.Fetzer@jpl.nasa.gov



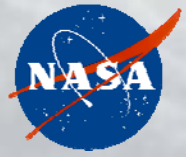
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Acknowledgements

- **The many people who created the tremendous A-Train data sets for studying the atmospheric water cycle from:**
  - ***AIRS***
  - ***AMSR-E***
  - ***CERES***
  - ***CloudSat/CALIPSO***
  - ***MLS***
  - ***MODIS***
  - ***TES***

Eric.J.Fetzer@jpl.nasa.gov



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Special thanks to many co-authors:

- Bob Atlas
- George Aumann
- John Barnes
- Chris Barnet
- Tim Barnett
- Ralf Bennartz
- Amy Braverman
- Dave Bromwich
- Mous Chahine
- Luke Chen
- Tony Clough
- Ted Cress
- Manuel de la Torre Juarez
- Sergio DeSouza-Machado
- Murty Divakarla
- Annmarie Eldering
- Wayne Feltz
- Evan Fishbein
- Lucien Froidevaux
- Mike Garay
- Catherine Gautier
- Andrew Gettelman
- Stephanie Granger
- Mitch Goldberg
- Mike Gunson
- Denise Hagan
- Bob Herman
- Mark Hofstadter
- Bill Irion
- Jonathan Jiang
- Ramesh Kakar
- Brian Kahn
- Eugenia Kalnay
- Bob Knuteson
- Bjorn Lambrigtsen
- Sung-Yung Lee
- John Le Marshall
- Barry Lesht
- Kuo-Nan Liou
- John Livingston
- Gloria Manney
- Jim Margitan
- Wallace McMillan
- Larry McMillin
- Peter Minnett
- Leslie Moy
- Shaima Nasiri
- Mike Newchurch
- Edward Olsen
- Tom Pagano
- Dave Pierce
- Jasna Pittman
- Bill Read
- Vince Realmutto
- Hank Revercomb
- Karen Rosenlof
- Phil Rosenkranz
- Michelle Santee
- Bhaswar Sen
- Frank Schmidlin
- Michael Schwartz
- Bill Smith
- Dave Staelin
- Larrabee Strow
- Hui Su
- Joel Susskind
- Dave Tobin
- Holger Vömel
- Von Walden
- Duane Waliser
- Bin Wang
- Joe Waters
- Chris Webster
- Dave Whiteman
- Walter Wolf
- Dong Wu
- Hengchun Ye
- Jim Yoe
- Zhou Zhang

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Offer Ends Tomorrow!
by Andy Dessler, Brian Kahn and Me

We still welcome submissions to our AGU Session:

A37: Atmospheric Feedbacks and Climate Change: Necessary Observations and Modeling Improvements

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Today's Themes

- **The IPCC models are not consistent with the observed means in temperature and water vapor**
  - ***What are the implications for feedbacks and model cloud physics?***

- **How close are we to creating a meaningful water vapor trend from the A-Train?**
  - ***Can we create a consistent record from all sensors to test water vapor feedbacks from greenhouse gas increase?***

***My conclusion*: We won't resolve these issues without understanding clouds and water vapor together.**

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Cloud Quotes #1

I bring fresh fresh showers for the thirsty flowers
For the seas and the streams…

- Percy Shelley, 'The Cloud'

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Cloud Quotes #2

We'll float around and hang out on clouds
then we'll come down and have a hangover.

-Kurt Cobain, 'Dumb'

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Background Reading

- **"Understanding Climate Change Feedbacks", National Research Council, 2003.**

- **Stephens, G. L., (2005) Cloud feedbacks in the climate system: A critical review, *J. Clim., 18,* 237-273.**

- **Bony, S., R. Colman, V. M. Kattsov, R. P. Allan, C. S. Bretherton, J.-L. Dufresne, A. Hall, S. Hallegatte, M. M. Holland, W. Ingram, D. A. Randall, B. J. Soden, G. Tselioudis and M. J. Webb, (2006), How well do we understand and evaluate climate change feedback processes?, *J. Clim., 19*, 3445-348.**

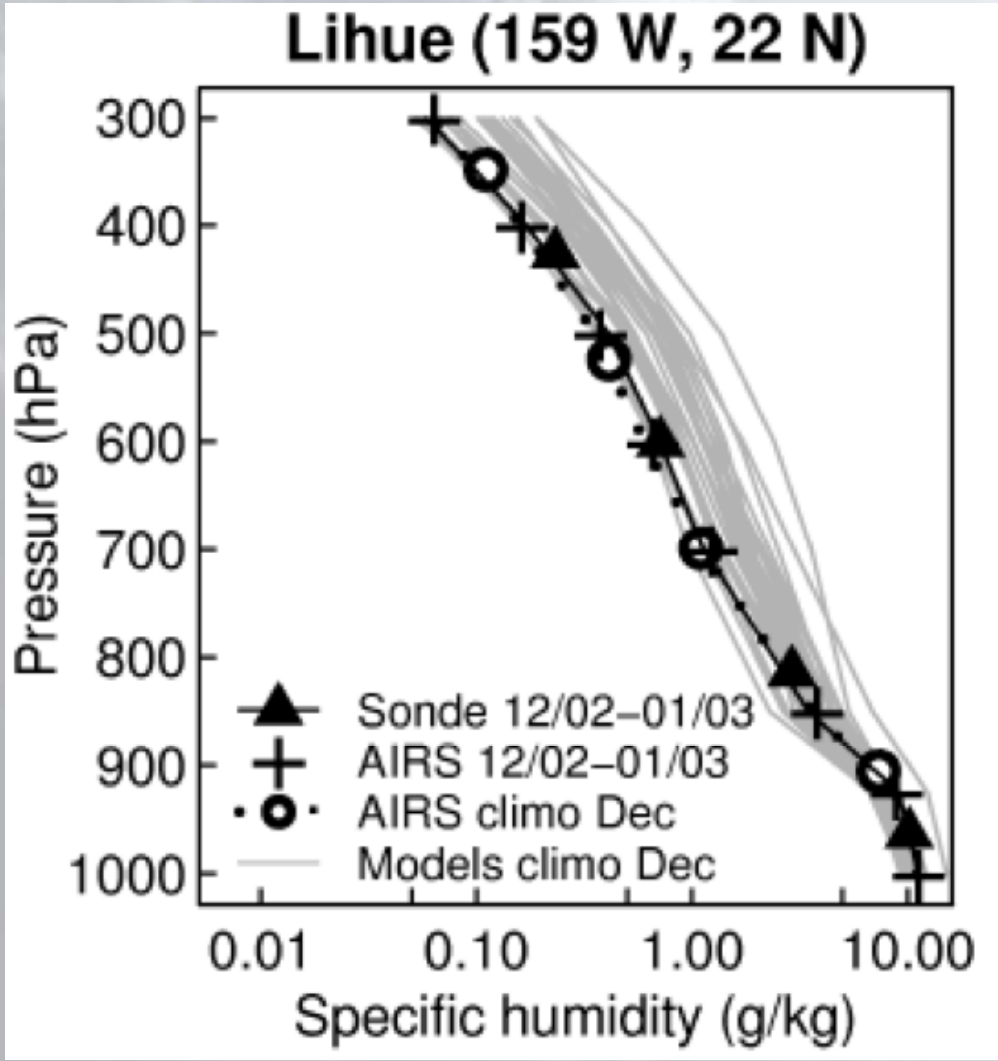
Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Theme one: Inconsistency of Models with Observed Means

Mean Climatologies of AIRS and 17 IPCC AR 4 Models.



From:

Pierce, D. W., T. P. Barnett, E. J. Fetzer, and P. J. Gleckler (2006), Three-dimensional tropospheric water vapor in coupled climate models compared with observations from the AIRS satellite system, *Geophys. Res. Lett., 33,* L21701, doi:10.1029/2006GL027060.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

All IPCC models have inconsistent mean T and q (as determined by obs).

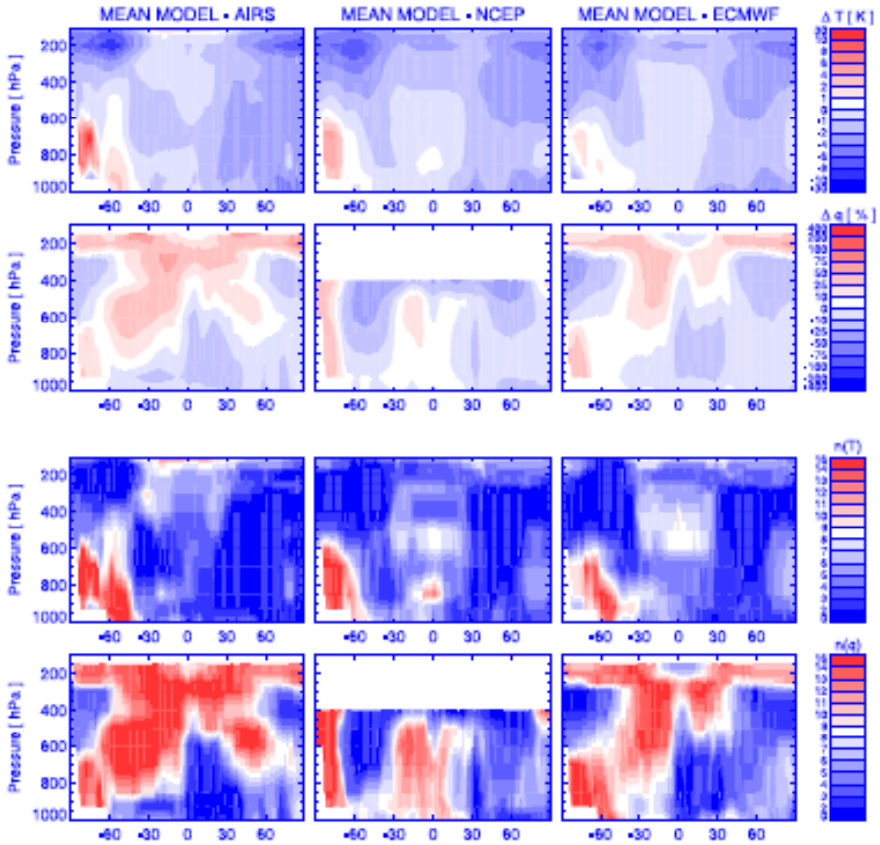


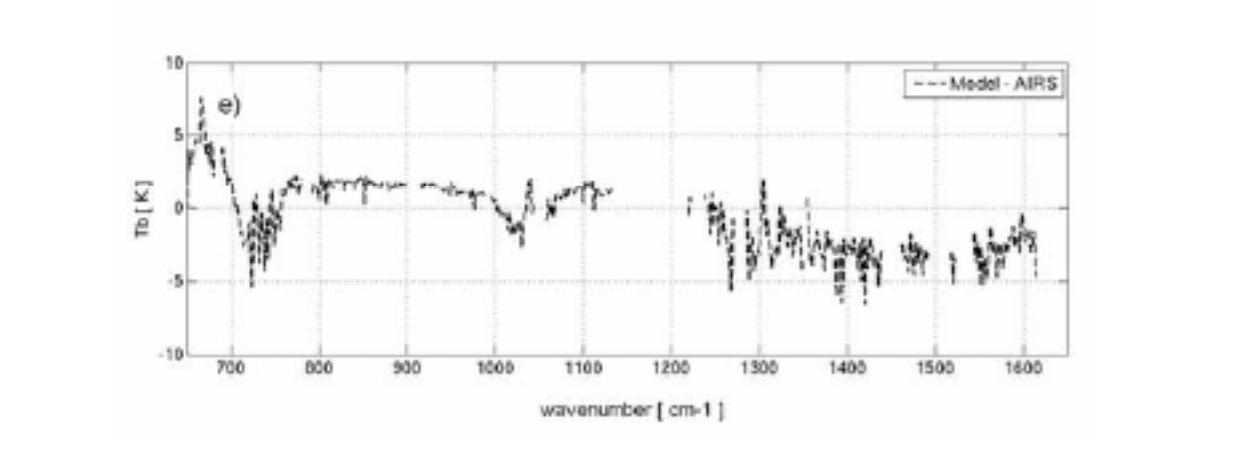
Figure 1. Vertical structure of difference in zonal averaged fields: (row 1) $\Delta T = T_{\text{model}} - T_{\text{obs}}$ and (row 2) $\Delta q = 100 \times \frac{q_{\text{model}} - q_{\text{obs}}}{q_{\text{obs}}}$. Note that in NCEP data set humidity values are not given above 300 hPa. These quantities for each coupled model are shown in Figures S1 and S2. Rows 3 and 4 show the number of models in which the simulated variable (T and q, respectively) is larger than the observed value. Values at either extreme of this range (all models or few models), indicate a robust positive or negative bias respectively.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Model OLR is correct, radiance spectral distribution is not



Abstract:...Radiance discrepancies in the water vapor v2 (1300–1650 cm 1) and carbon dioxide v2 (650–720 cm 1) bands are consistent with the model biases in atmospheric temperature and water vapor. The existence of radiance biases of opposite signs in different spectral regions suggests that a seemingly good agreement of the model's broadband longwave flux with observations may be due to a fortuitous cancellation of spectral errors. Moreover, an examination of the diurnal difference spectrum indicates pronounced biases in the model-simulated diurnal hydrologic cycle over the tropical oceans, a feature seen to occur in other GCMs as well.

Huang, Y., V. Ramaswamy, X. Huang, Q. Fu, and C. Bardeen (2007), A strict test in climate modeling with spectrally resolved radiances: GCM simulation versus AIRS observations, *Geophys. Res. Lett.*, *34*, L24707, doi:10.1029/2007GL031409.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Water vapor and lapse rate feedbacks vary, but independently of T and q details

John and Soden, GRL, 2007

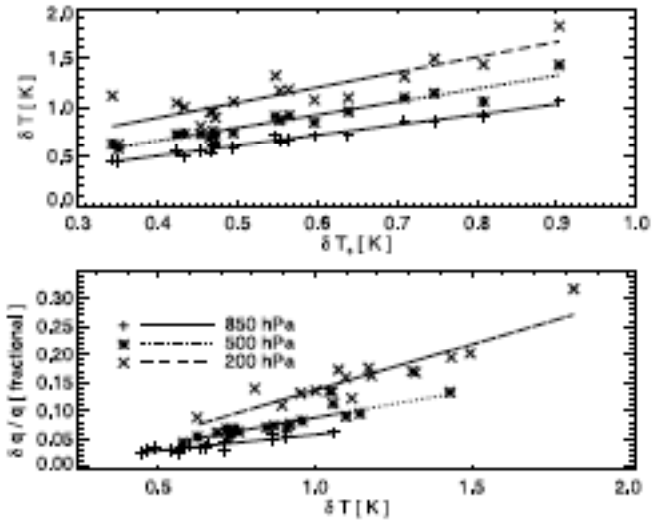


Figure 2. (top) Response of T at three different atmospheric levels (850, 500, and 200 hPa) to change in surface temperature (T_s). (bottom) Fractional response of q at three different atmospheric levels (850, 500, and 200 hPa) to change in T at those levels. Different symbols represent different coupled GCMs used in this study. Tropical means are used. δT, δT_s, and $\frac{\delta q}{q}$ are the difference between the first 10 year and the last 10 year means of 20th century of each variable.

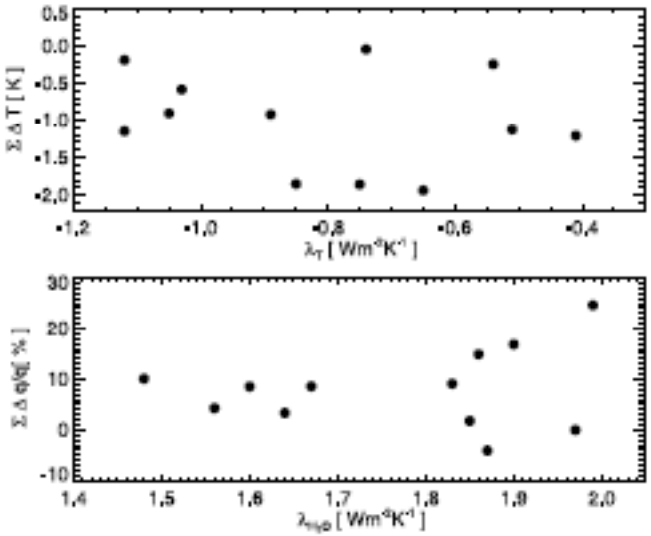


Figure 3. (top) Vertically integrated global mean T biases from 1000 to 100 hPa in the models versus temperature lapse-rate feedback (λ_T). (bottom) Vertically integrated fractional q biases from 850 to 200 hPa versus water vapor feedback (λ_{H_2O}). The feedback values simulated by the models are taken from *Soden and Held* [2006].

All models respond positively to increasing surface T.

All models are too cold (top) & too wet at 850-200 hPa (bottom). But model feedback strengths are uncorrelated with T & q diffs.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Biases do matter for chemistry

What about cloud physics????

O'Connor, F. M., C. E. Johnson, O. Morgenstern, and W. J. Collins (2009), Interactions between tropospheric chemistry and climate model temperature and humidity biases, *Geophys. Res. Lett.*, 36, L16801, doi:10.1029/2009GL039152.

From abstract:

"Removing the humidity bias alone causes a reduction in both the global annual mean tropospheric ozone burden of greater than 2% and the methane lifetime of 3.6–4.2%."

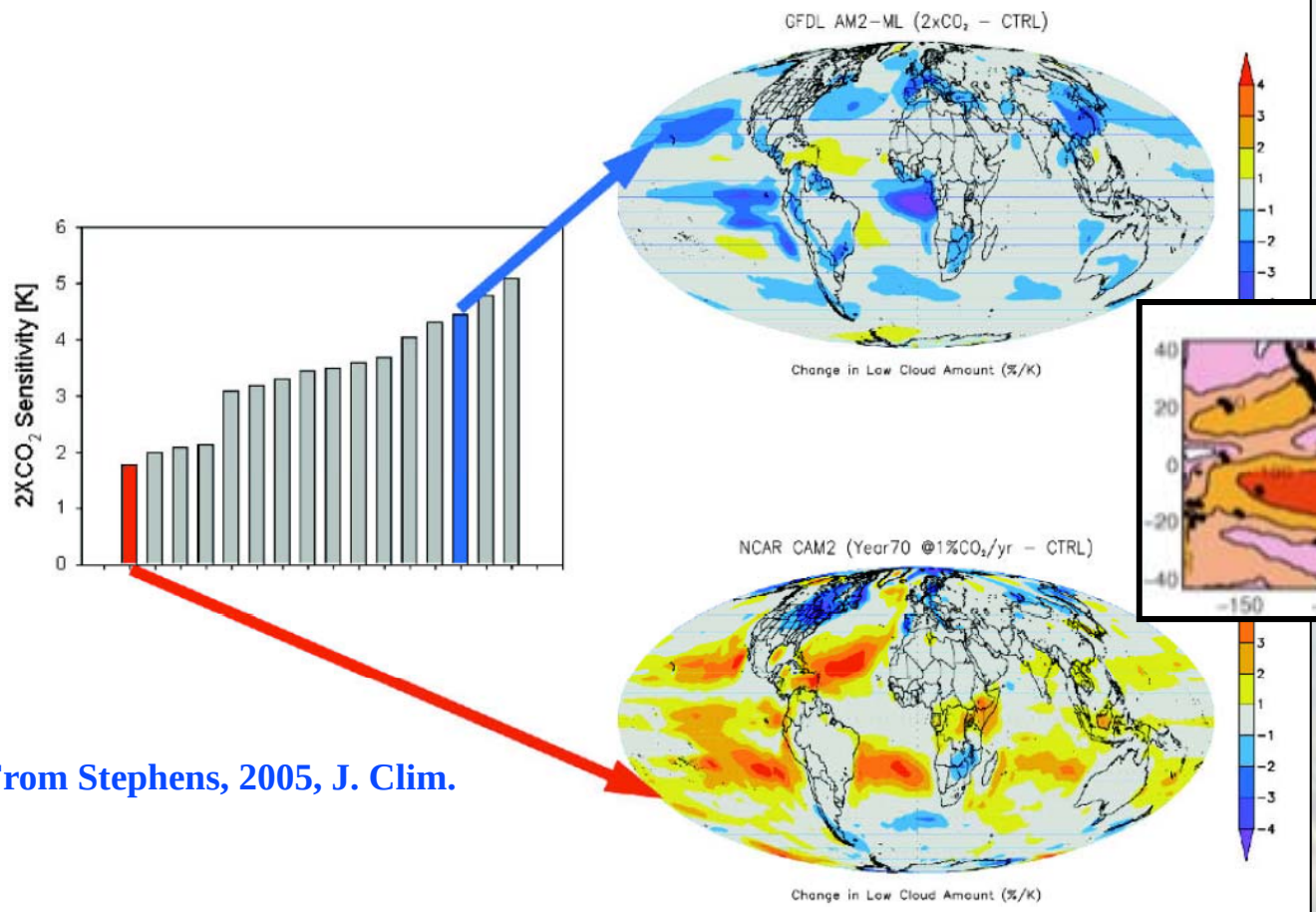
Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Why biases might matter for clouds

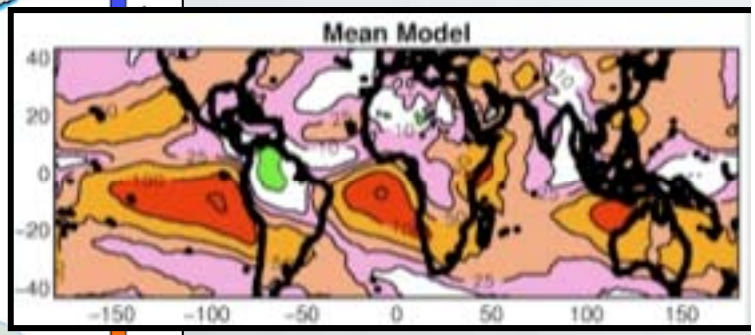
IPCC model humidity biases are collocated with the most uncertain clouds.



From Stephens, 2005, J. Clim.

FIG. 1. The response of a number of present-day climate models forced by a 1% yr^{-1} increase of CO_2. Shown is the difference of the 20-yr average of the simulation with fixed and increasing CO_2. The averages are over years 1961–80; corresponding broadly to the time of a CO_2 doubling. To the right are the changes to low clouds averaged over this same period for two models that fall on either end of the projected warming range (courtesy of B. Soden).

Model humidity biases, 400 hPa



From Pierce et al., 2007.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Conclusions: model biases and feedbacks

- **IPCC model temperature and humidity biased in the mean against AIRS and reanalyses; also seen in spectra**
  - ***Largest biases where low cloud feedbacks are most uncertain!***

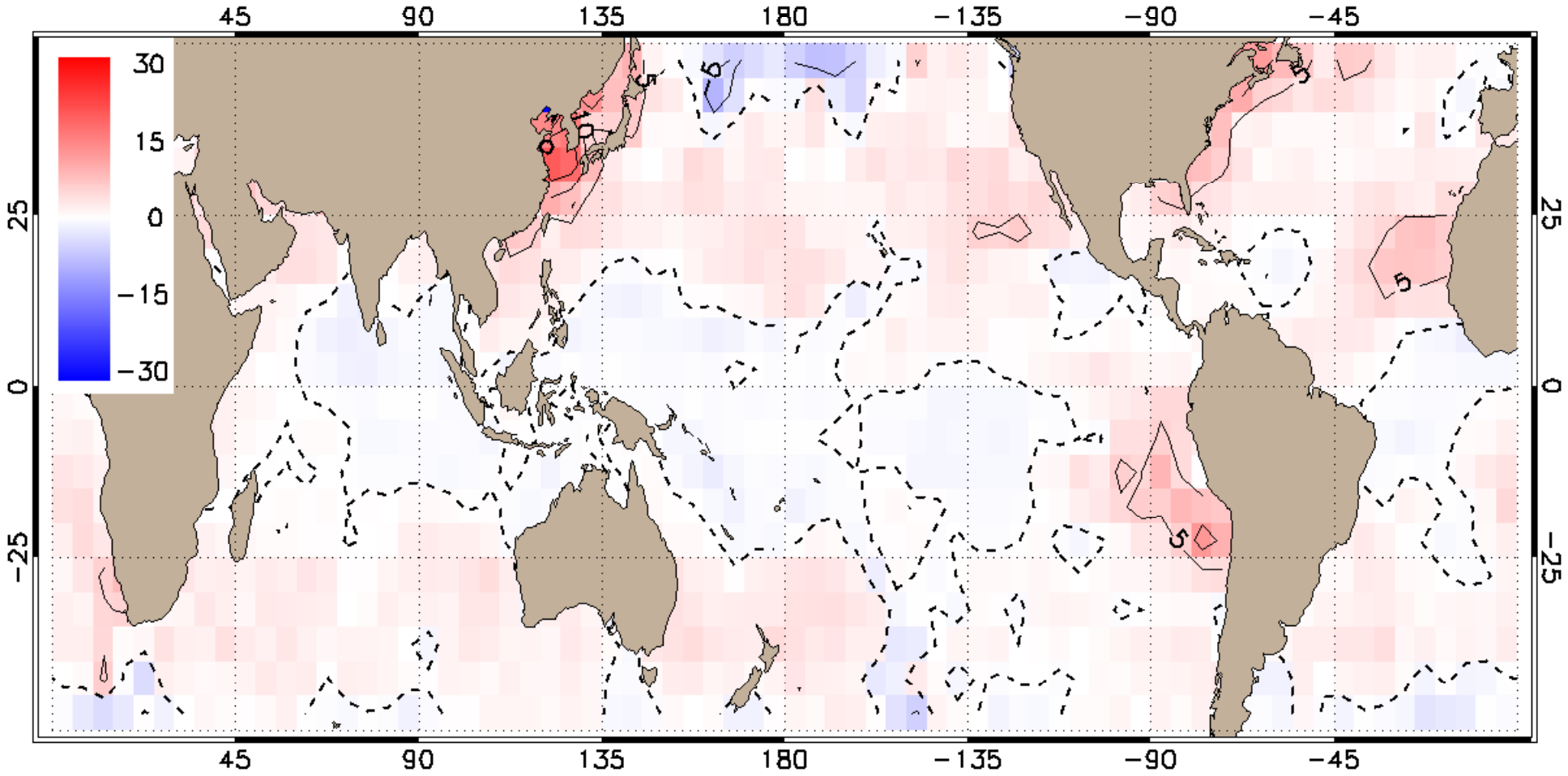
- **BUT, models are consistent with multi-decadal observations**
  - ***SSM/I total water vapor.***
  - ***$T_{6..3\ \mu m}$ radiances from TOVS and GOES***
  - ***OLR from CERES***

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Creating a Long-Term Record *The Good News:* A-Train Sensors are Consistent for Mutually-Observed Scenes



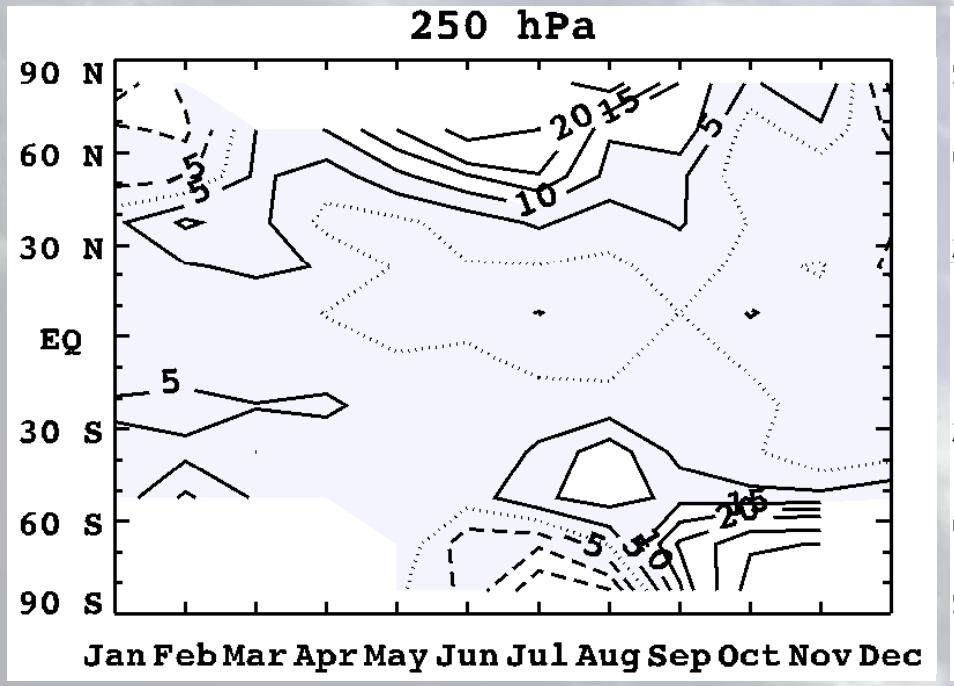
Eric.J.Fetzer@jpl.nasa.gov

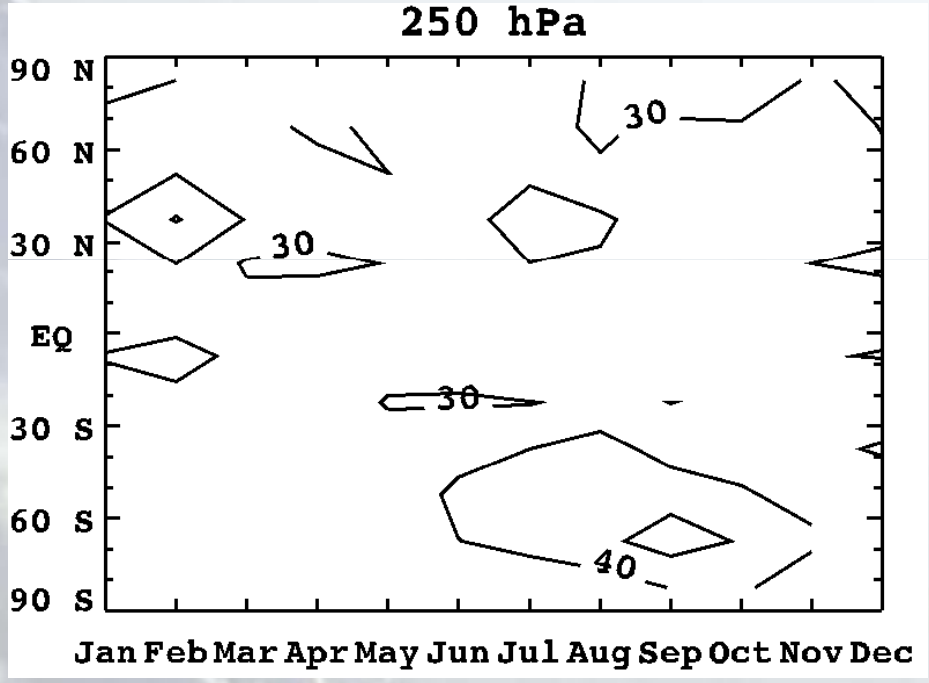
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

More agreeing measurements: AIRS and MLS Water Vapor at 250 hPa

Matched obs. for twelve months in 2005, twelve zonal bands.





Biases: ±10% values shaded.

RMS of differences

Eric.J.Fetzer@jpl.nasa.gov

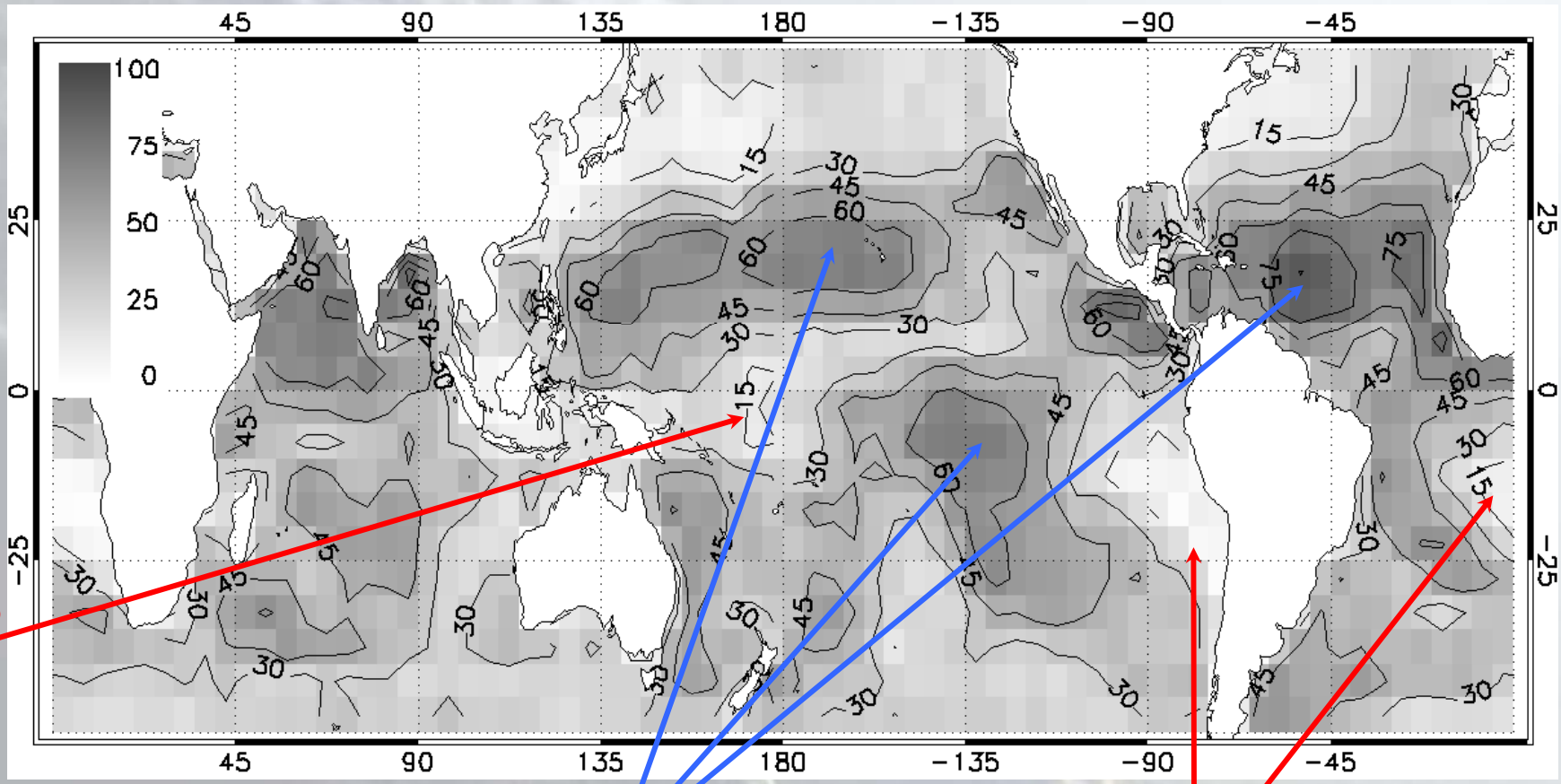
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

AIRS retrieval yields vary with location

Fraction of 'good' retrievals (percent)

25 Dec 2002 to 15 Jan 2003



!!??

Highest yields in trade cumulus.
Good news for Fetzer et al. 2004.

Poorer coverage in stratocumulus; use with caution here.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

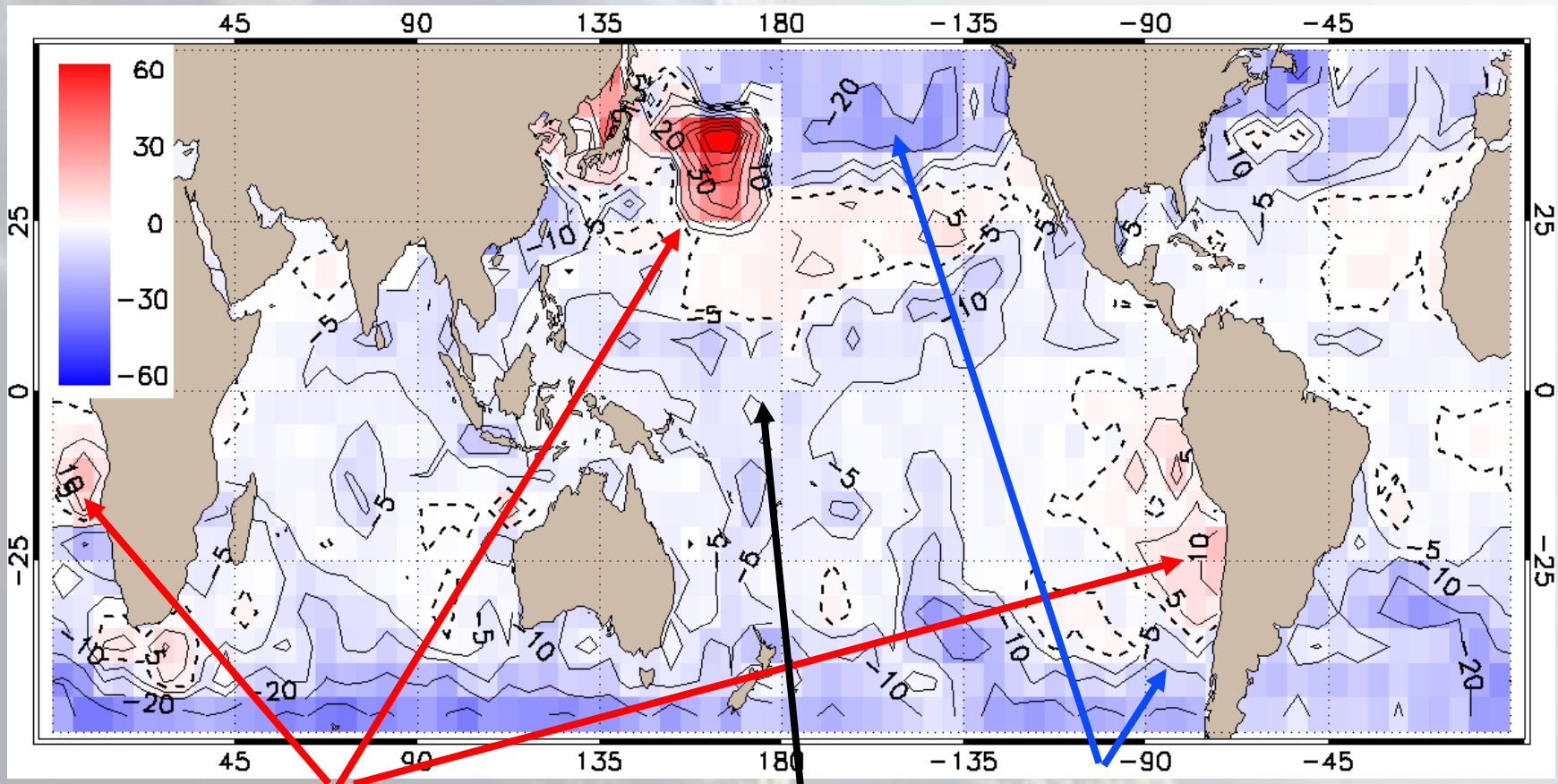
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Percent Differences in Mean Water Vapor Climatologies

AIRS can be drier OR wetter than AMSR-E

because of cloud-induced sampling effects

25 Dec 2002 to 15 Jan 2003



AIRS climatology is *wetter* than AMSR-E in stratus regions

Small difference in tropics !!??

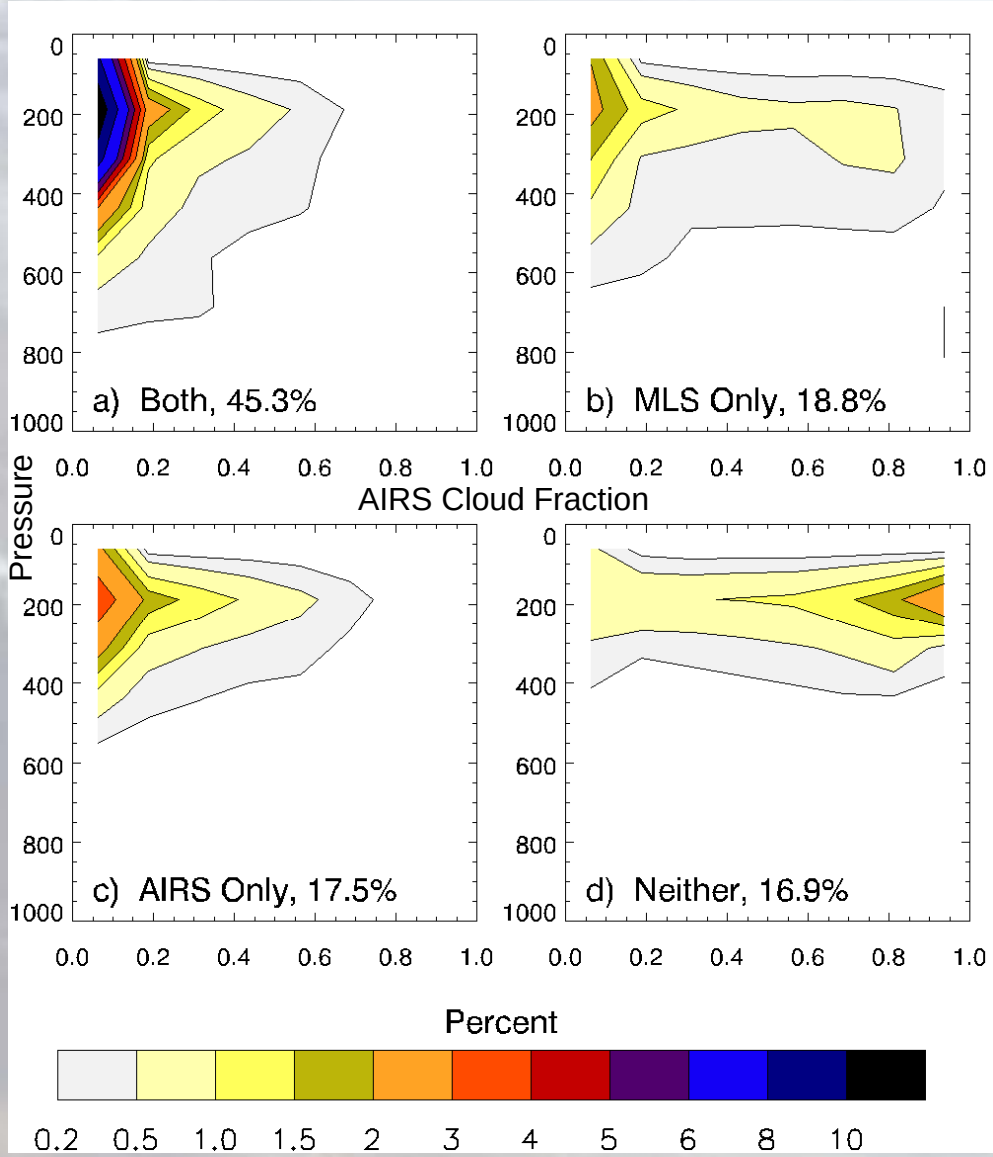
AIRS climatology is *drier* than AMSR-E at high latitudes

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Both AIRS and MLS preferentially sample clear scenes in tropics



Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Sampling biases can be important

Exit Polling during 1948 presidential election lead to headline “Dewey Defeats Truman.”

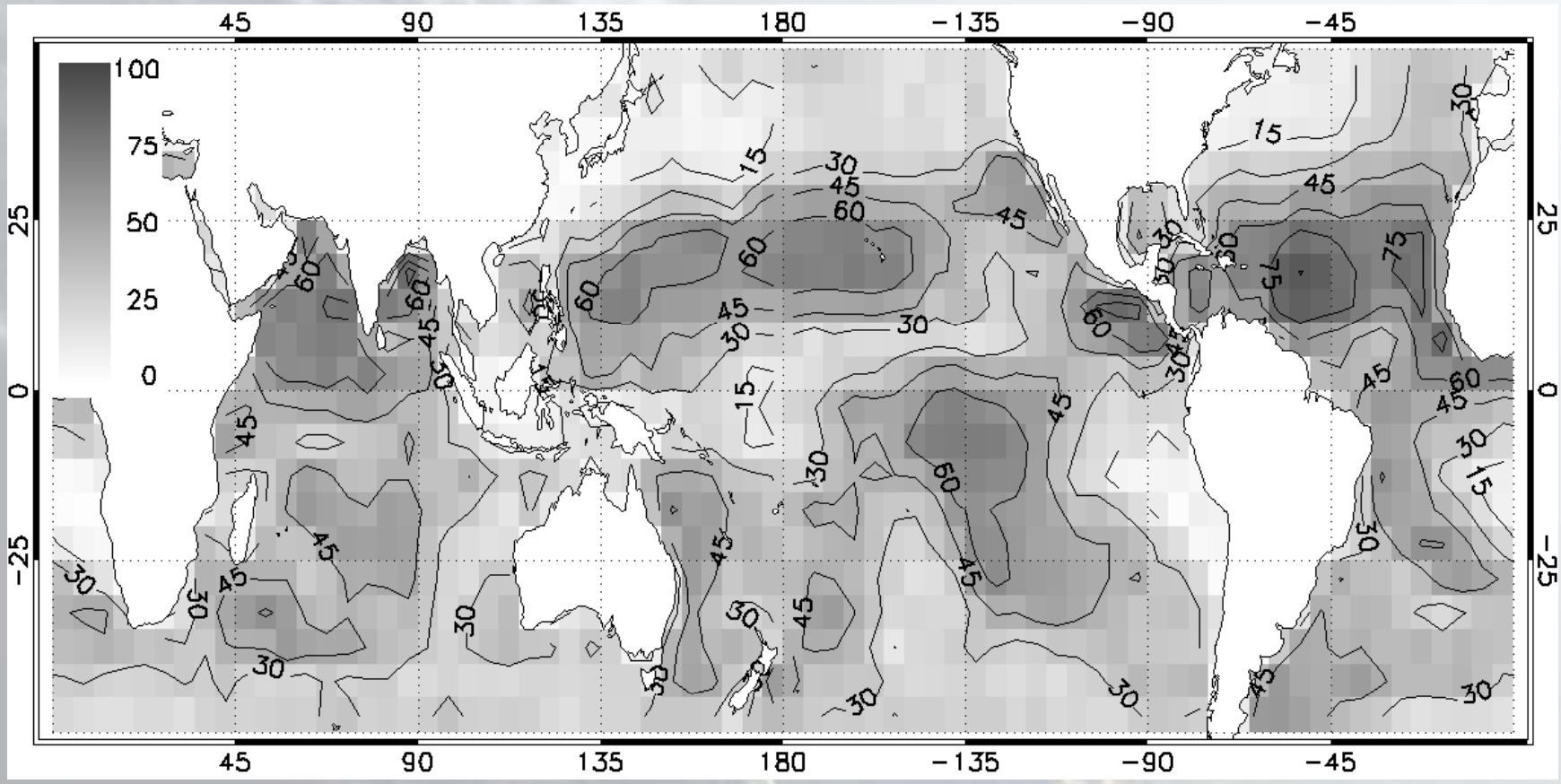
Statistician call this the ‘error of representativeness’; concerned since roughly November 1948.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Your Challenge: Calculate the mean over this sample.



AIRS Yields

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Next

- **Can we create a merged, reconciled record of water vapor from all sensors, but relating clouds and water vapor?**
  - ***NASA MEaSUREs program is funding us.***

- **We are coordinating with the NVAP project.**
  - ***We will provide a 'seamless' record between earlier sensors (TOVS, SSM/I) and A-Train.***
    - *Our Grand Goal*: Extend back into the disco-era TOVS data.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Some Questions

- **Can we simultaneously monitor water vapor and changes in its viewing conditions (due to clouds in the IR, precip in the MW), over years to decades?**

- **How do moist thermodynamics vary with cloud state?**
  - ***Climate model physics is regime dependent.***

- **Is the relationship between cloud state and water vapor universal?**

- **How dominant are effects in the radiatively important middle and upper troposphere?**

- **How precise and accurate should earlier sounders be to separate trends in water vapor by cloud state?**
  - ***Assuming cloud state can be well characterized by ISCCP or similar observations.***

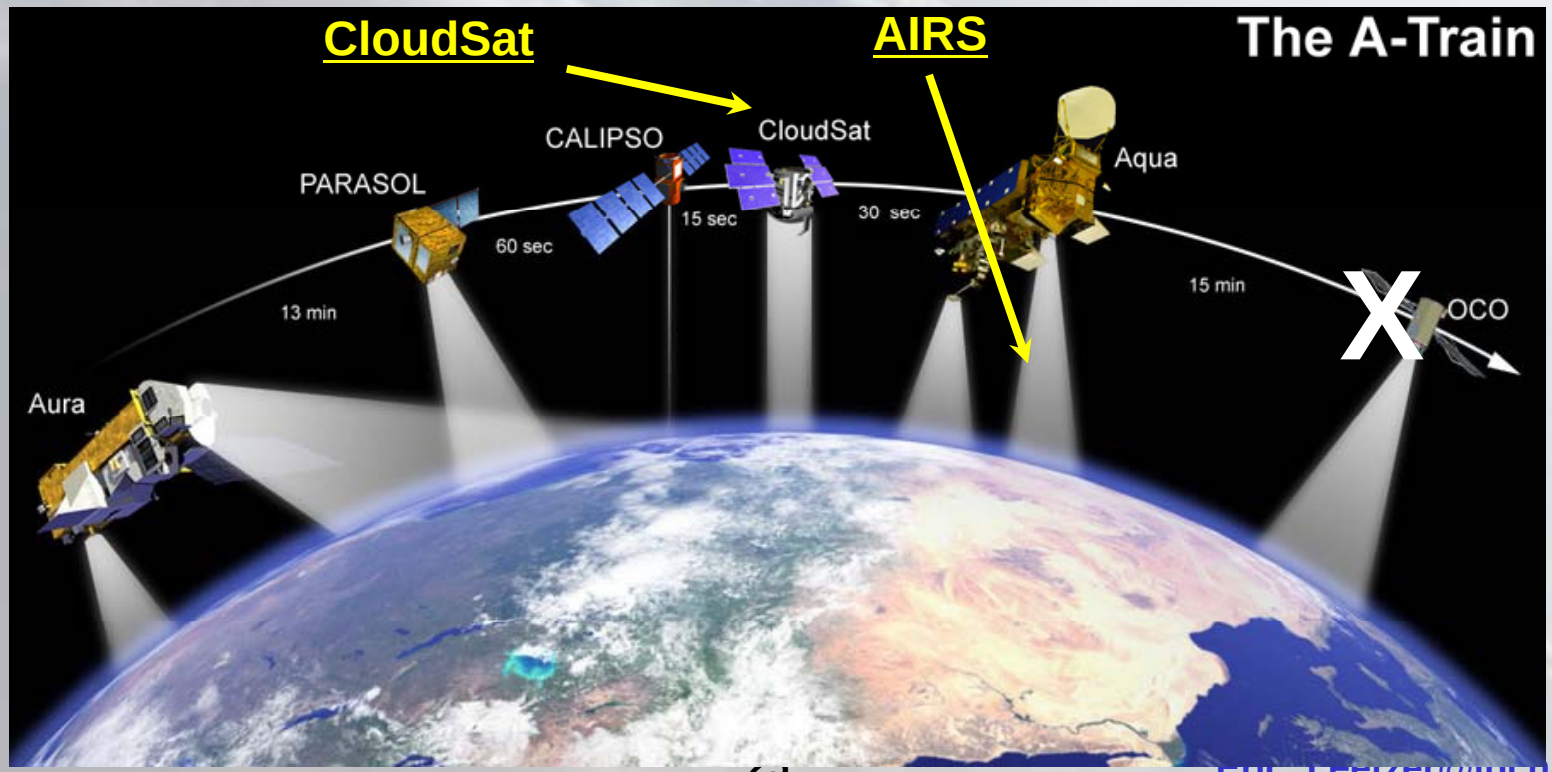
Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Showing Data from Two *Independent* Instruments

1. **AIRS water vapor profiles.**
2. **CloudSat cloud classes overlie AIRS near nadir.**



Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Relate Cloud State and Water Vapor Tropics 15S-15N, Oceans Only

Why only the tropics?

- **Water vapor feedbacks strongest there.**
- **The following CloudSat groupings easily account for most AIRS scenes in the deep tropics:**
  - ***Shallow convection (three classes).***
  - ***Deep convection (five classes).***
  - ***Few unclassified scenes remain.***

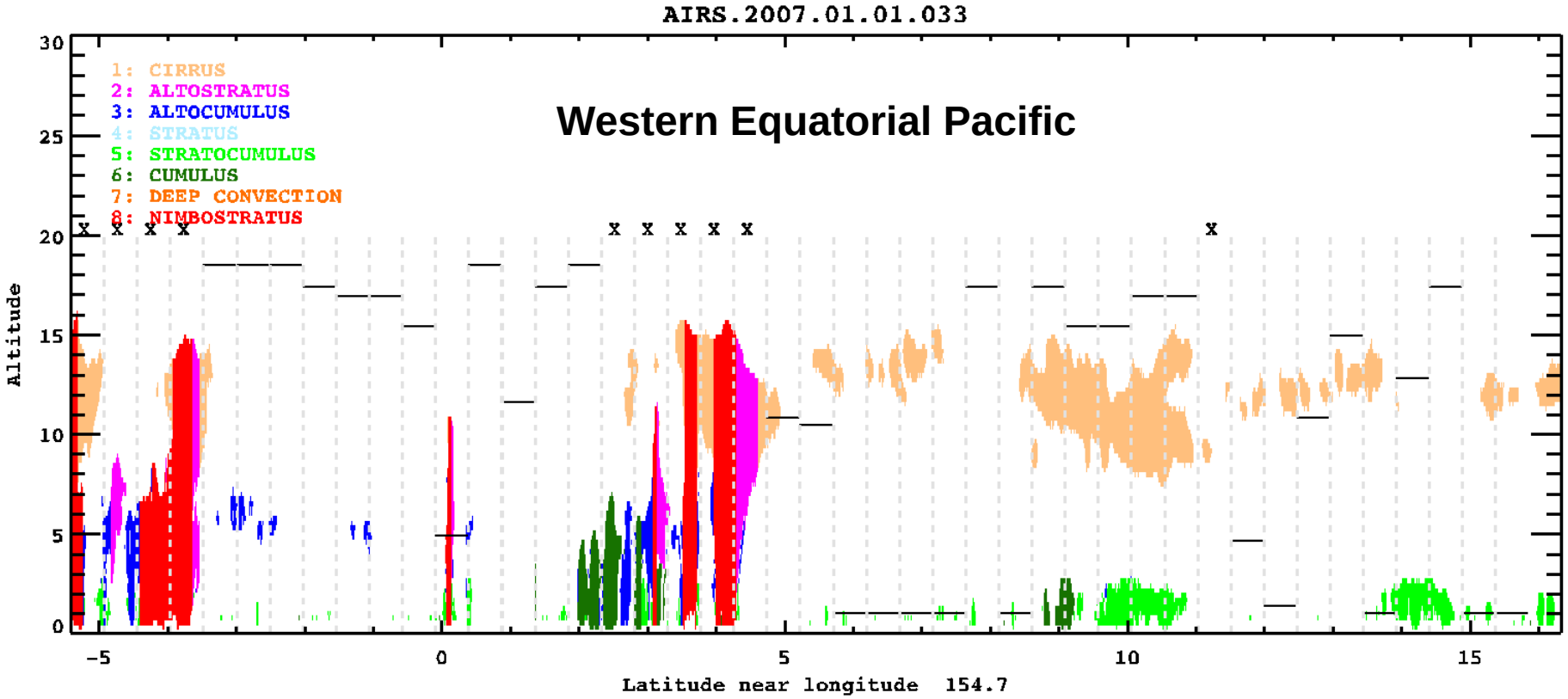
Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

AIRS-CloudSat Matched Data

Color fill = CloudSat Class (Sassen and Wang, 2008, GRL)



Black lines: AIRS 'best' retrieval altitude
X: no AIRS tropospheric profiling.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

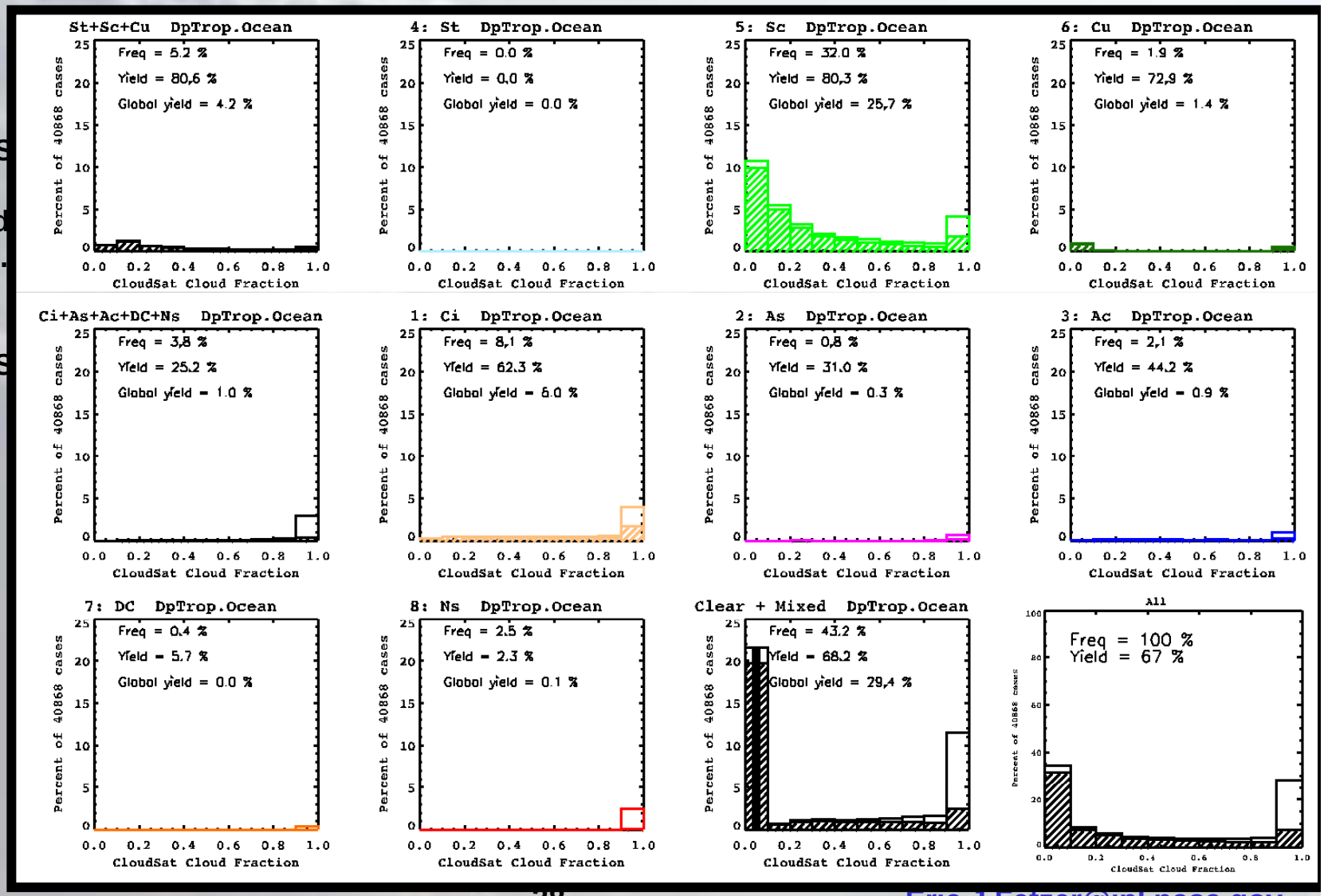
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Relating AIRS retrieval performance to CloudSat cloud class and fraction

January 2007, 15S-15N, Ocean only

No Fill:
percent of AIRS scenes of that CloudSat cloud type & fraction.

Fill:
percent of AIRS scenes with retrieval to surface.



Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Confirming AIRS Retrieval Performance Varies with CloudSat Cloud Class

1) Shallow Clouds

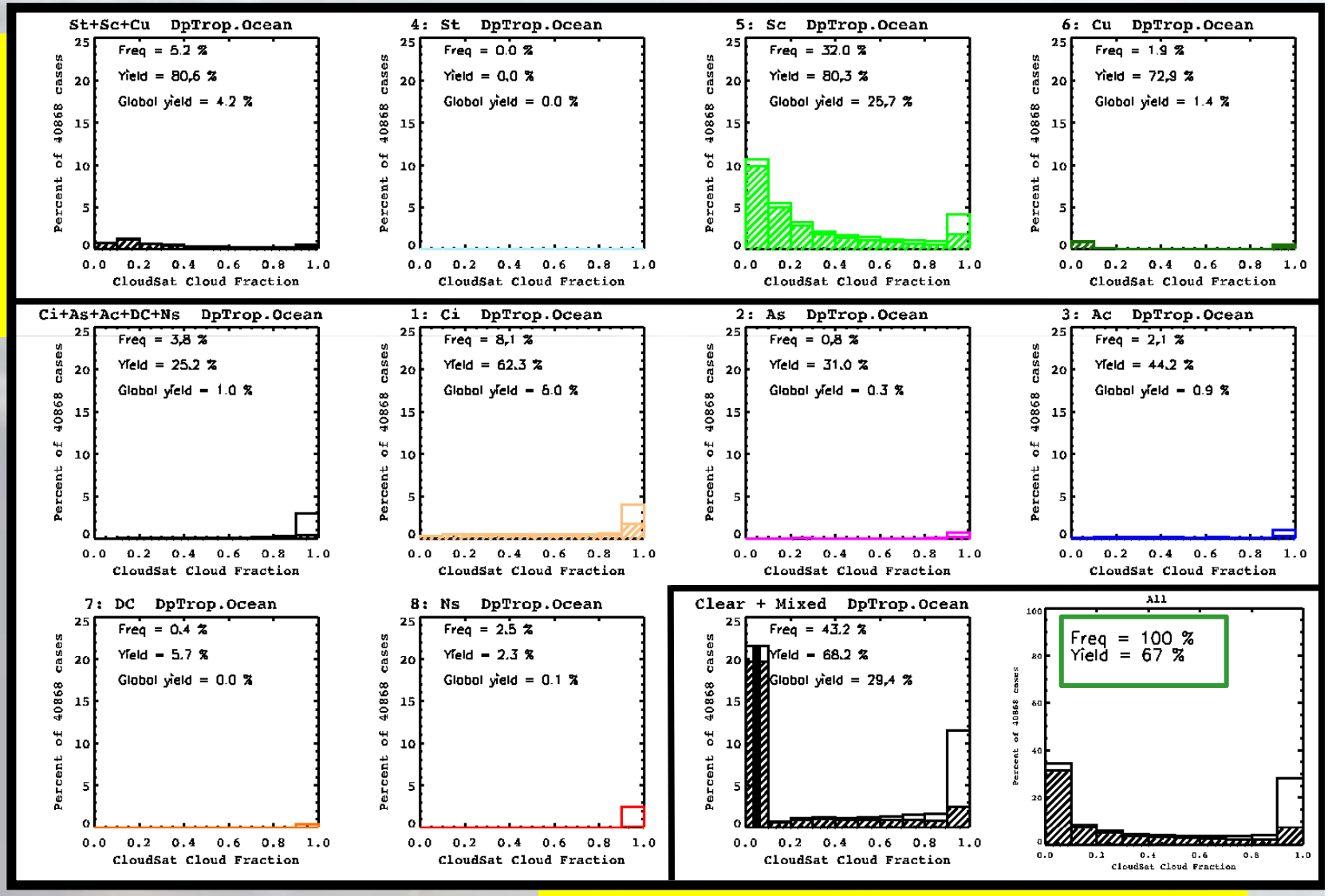
40% of all scenes

Yields are ~80%.

2) Deep Clouds

17% of all scenes

Yields are ~2 to 63%.



3) Clear & Mixed; ~43% of scenes; Yield is 68%.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

AIRS Mean Water Vapor by Classes

January 2007, 15S-15N, Ocean only

1) Shallow Clouds

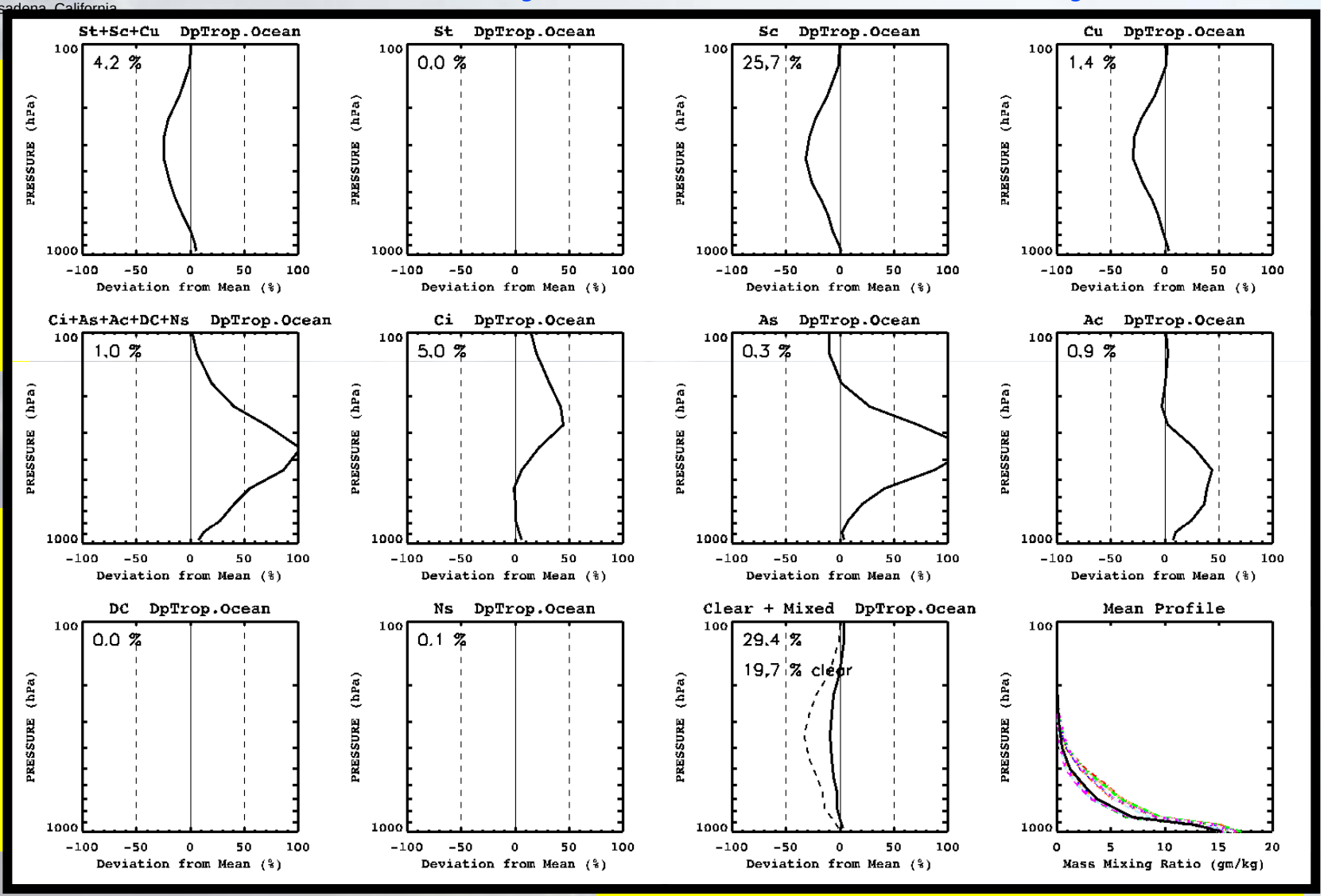
40% of all scenes

Yields are ~80%.

2) Deep Clouds

17% of all scenes

Yields are ~2 to 63%.



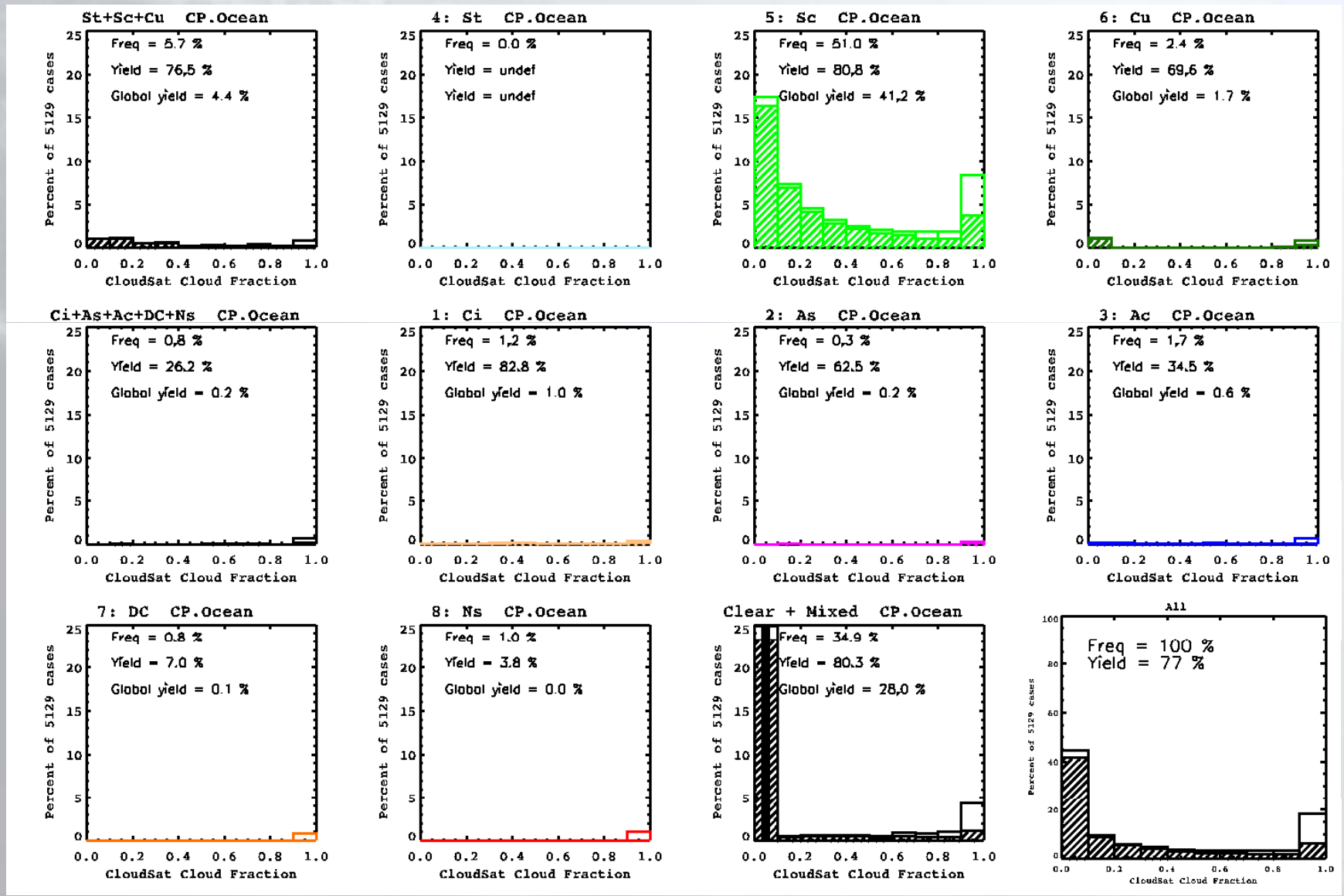
***3) Clear & Mixed; ~43% of scenes;* Yield is 68%.**

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Moving to E. Pacific Cool Pool

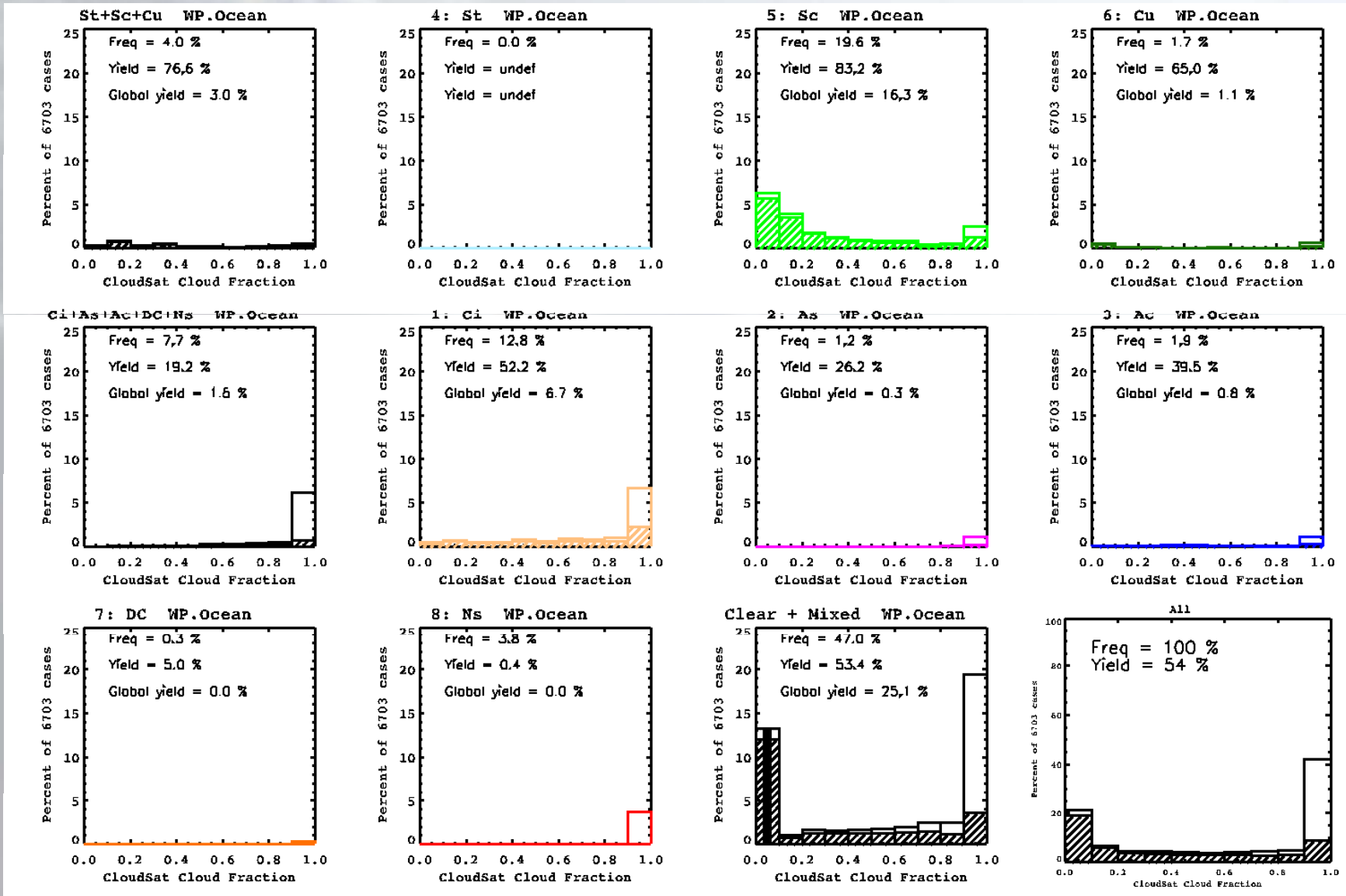


Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

W. Pacific Warm Pool

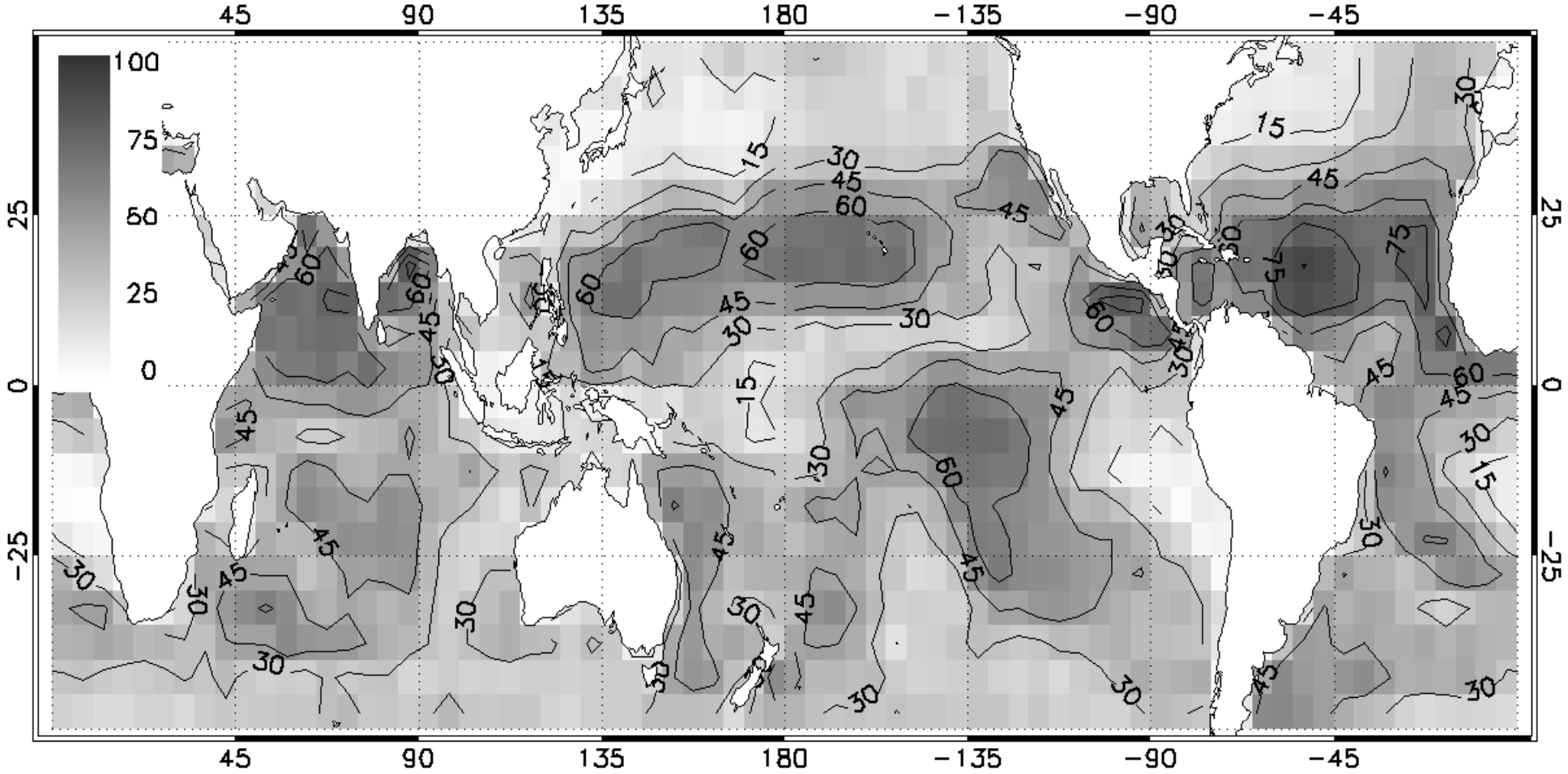


Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

High yields in the E. Pacific due to prevalence of shallow, broken clouds.
Low yields in W. Pacific due to prevalence of deep, thick clouds.



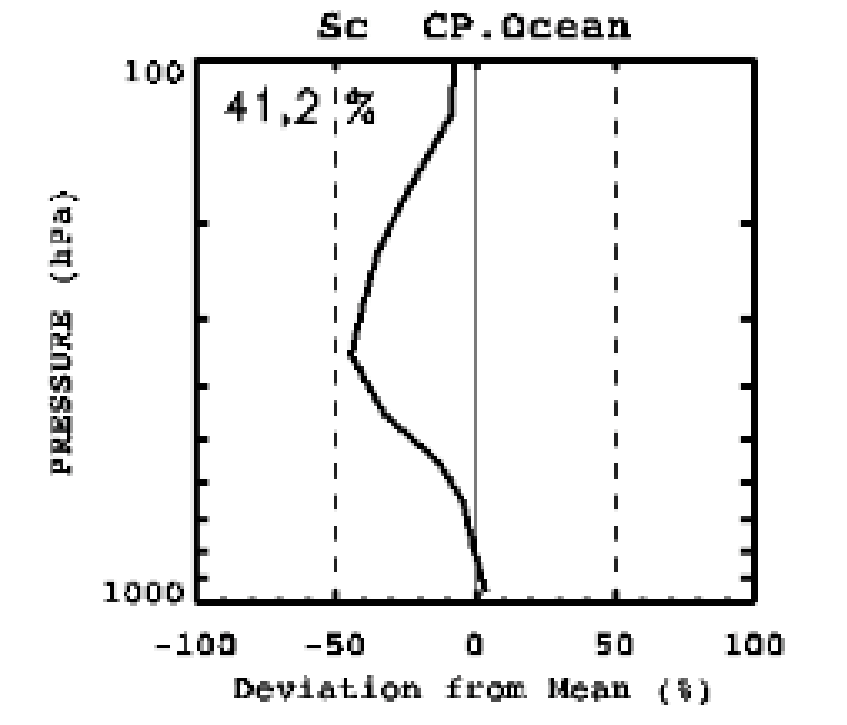
Eric.J.Fetzer@jpl.nasa.gov

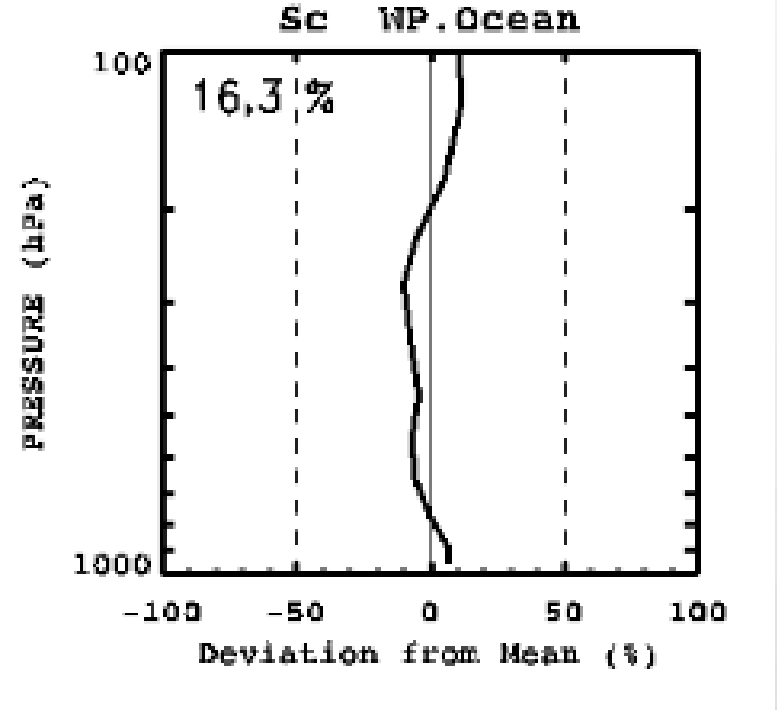
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

No Universal Water Vapor Profile by Cloud State

Mean AIRS water vapor profiles for CloudSat Stratocumulus class, relative to the tropical mean

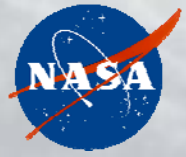




E. Pacific Cool Pool

W. Pacific Warm Pool

Eric.J.Fetzer@jpl.nasa.gov



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Answering Today's Questions

- **Can we simultaneously monitor water vapor and changes in its viewing conditions (imposed by clouds in the IR)?**
  - ***Yes, with deep convection most challenging in the tropics.***

- **How do moist thermodynamics vary with cloud state?**
  - ***Water vapor varies up to 200% between states.***

- **Is the relationship between cloud state and water vapor universal?**
  - ***No. Example: shallow convection in the Warm Pool has a wetter free troposphere than shallow convection in the Cool Pool.***
    - Surface humidity is trivially universal: roughly constant.

Eric.J.Fetzer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Answering Some Questions (cont'd)

- **How dominant are effects in the radiatively important middle and upper troposphere?**
  - ***Most of the water vapor variations between cloud states occur in the middle and upper troposphere.***

- **How precise and accurate do earlier sounders need to be to separate trends in water vapor by cloud state? Assuming cloud state can be well characterized by ISCCP or similar observations.**
  - ***Don't know, yet, but distinguishing deep and shallow convection may require ~25% biases.***

Eric.J.Fetzer@jpl.nasa.gov